

Preliminary Results of an Experimental Investigation of the Qu Superconducting Heat Pipe

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Nomenclature

h	=	heat transfer coefficient ($\text{W/m}^2\text{-K}$)
P	=	perimeter (meter)
A_c	=	area of cross section (meter^2)
k	=	thermal conductivity of the copper tube (339 W/m-K)
$T(x)$	=	temperature along the tube, degrees C
T_{amb}	=	temperature of the air, degrees C
T_b	=	temperature at base, degrees C
L	=	length of rod or tube (meters)
d_o	=	outer diameter of tube (meters)
d_i	=	inner diameter of tube (meters)

I. Introduction

THIS note on preliminary results of our evaluation of the so-called Qu Tube¹⁻⁴ is prompted in part by recent concerns expressed to the authors by some researchers regarding the performance characteristics of the superconducting, solid-state heat pipe as described in the patents, or on the company's website⁵. Briefly, the company's claims include: a new type of heat transfer mechanism that is a form of solid state thermal superconductivity, which results in an effective thermal conductivity of the order of tens of thousands of times that of an equivalent solid silver bar, or, tens to hundreds of times that of liquid – vapor heat pipes. The company's website also refers to tests conducted by Stanford Research Institute that substantiate these claims, but the report is apparently not publicly available. We are conducting an investigation of the Qu Tube under a NASA Grant, and in general find that these claims have merit, but our study is not yet complete. We present some of our preliminary results in part to show that it would not be imprudent to conduct such studies, especially for possible future applications requiring exceptional thermal management performance capabilities.

Working with HiTek Services, we originally acquired several Qu Tubes, including 17" long, 5/16" diameter copper tubes, one that is 7 7/8" long, 3/16" diameter, and one that is 4" long, 1" diameter. We subjected the smaller

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tubes to various exploratory tests, including a transient test with electrical band heaters, boiling water tests, and a series of steady state tests with electrical band heaters heating one end with free convective cooling along the remainder of the length. All results indicate a very high thermal conductivity, but the length of these tubes limited our ability to obtain accurate data on temperature gradients, necessary to determine the effective thermal conductivity. We then acquired nine Qu Tubes that are 10' long, 5/16" diameter, and we have recently conducted initial tests, which further support the claims of exceptional thermal conductivity.

II. Results and Discussion

Figure 1 shows the thermal response of the 17" long tube subjected to a step change in temperature for boiling water, with the tube vertical, cooled by free convection. The temperature transient is seen to compare well with the analysis of an equivalent "billet" exposed to boiling heat transfer at one end and to free convective cooling along the remainder of the length. It should be noted that the billet solution essentially assumes infinite thermal conductivity. There appeared to be a lag before part of the tube became "superconducting", and therefore we have plotted two cases for the billet analysis, which bracket the test data obtained. For comparison, we also plot the results for a copper rod, of the same diameter and length, as shown by the bottom two curves.

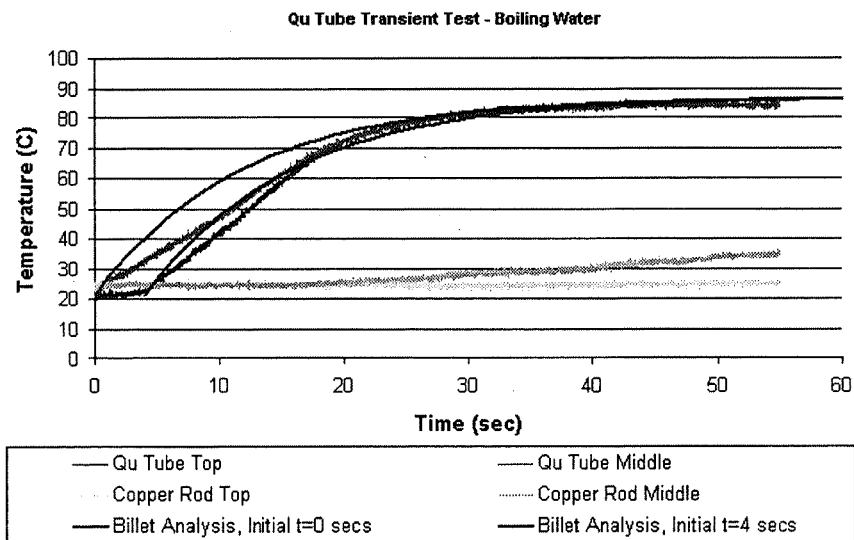


Fig. 1 Temperature response of Qu Tube and equivalent copper rod immersed in boiling water

Figure 2 shows the steady state temperature gradient along one of the 17" tubes, with one end heated by an electrical band heater. We show the comparison of the temperature gradient for an equivalent copper tube, and then

multiples of the copper thermal conductivity. It requires a multiple of at least 1000 to 10,000 times that of the thermal conductivity of copper to obtain the essentially constant temperatures measured along the Qu Tube, and thus this appears to be a lower bound on the effective thermal conductivity.

Figure 3 shows the same type of temperature gradient along one of the 10' Qu Tubes. Here, the effective thermal conductivity multiple is 10,000 to 30,000 times that of copper, to achieve the essentially constant temperature, within the approximately ± 2.2 degree C uncertainty in the thermocouple readings.

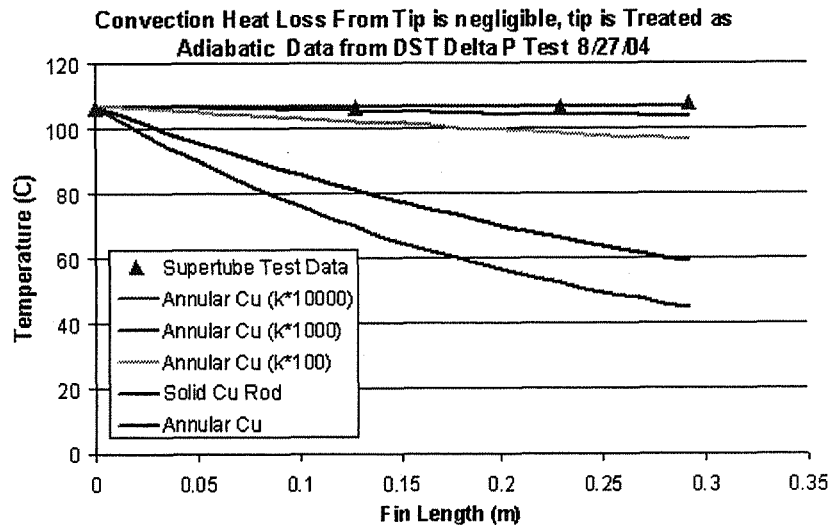


Fig. 2 Temperature distribution of 5/16" diameter, 17" long Qu Tube compared to copper rod, annulus, and multiples of the copper thermal conductivity

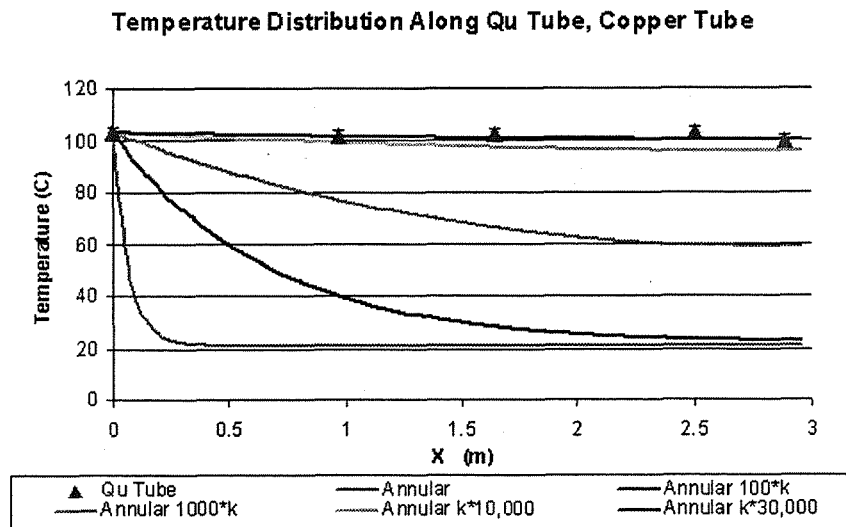


Fig. 3 Temperature distribution of 5/16" diameter, 10' long Qu Tube compared to copper rod, annulus, and multiples of the copper thermal conductivity

The fin equation used for these analytical plots is given⁶ as

$$d^2\Theta/dt^2 - m^2\Theta = 0$$

with the solution,

$$\Theta = C_1 e^{+mx} + C_2 e^{-mx}$$

where,

$$\Theta = T(x) - T_{amb},$$

$$\Theta_b = T_b - T_{amb}$$

$$m^2 = hP/kA_c,$$

For the case in which the heat transfer from the tip is negligible, the solution is

$$\Theta/\Theta_b = \cosh m(L - x)/\cosh mL.$$

For convenience, we plot $T(x)$ vs. x in Fig. 2 and Fig. 3 for the analyses and data comparisons.

We also became aware of certain substantial differences in the characteristics of the Qu Tubes. For example, we learned that some of the tubes had a gravity dependence: heated from below, with an angle of the order of 10 degrees from the horizontal, to 90 degrees (vertical), they behaved as Qu Tubes. Heated from above, however, they behaved as ordinary copper. Our 17" tubes had this characteristic, as illustrated in Fig. 4. Here, thermocouples are located at the distances shown from the swaged end of the tube; the opposite end is crimped and sealed, according to the description in the referenced patents, after the special materials are introduced into the tube. Figure 4 shows the temperatures along the tube are essentially identical, within the uncertainty of the thermocouple accuracy, with changes in orientation. For either end heated, with the tube pointed down, there was a substantial temperature gradient, whereas with either end heated, and the tube pointed up, there no detectable temperature gradient. However, the 3/16 diameter tube had the gravity independent characteristic, with an essentially constant temperature along its length, whether heated from either end, with the tube pointed up or down, as shown in Fig. 5. Briefly, the patents describe the process and materials used to form thin layers on the interior surface of the tube, inserting a combination of materials, and then sealing the tube. The purposes of these layers and materials are described in the referenced patents, together with comments regarding the solid state, superconducting thermal conductivity characteristics. However, we had encountered various objections to these assertions in our discussions with various investigators, including NASA and U.S. Air Force investigators, and we had our own concerns as to the actual heat transfer mechanism, performance, and contents of the tube. At this time, we had a limited number of

tubes and could not cut these open and still be able to conduct the tests planned as part of the Grant. We therefore x-rayed several of the tubes; we found that the 17" tubes and the 4" tube contained a wire mesh (see Fig. 6). Approximate measurements show that the mesh wire diameter is about 0.001" and the spacing is about 0.005". The x-rays also determined the wall thickness of the tube (approximately 0.032"), which was needed in our analyses. We have not been able to determine what the purpose of this wire screen is, but we could not see liquid in the tubes we x-rayed, and therefore we have found no evidence that these tubes are conventional liquid-vapor heat pipes, or pool boiling heat pipes.

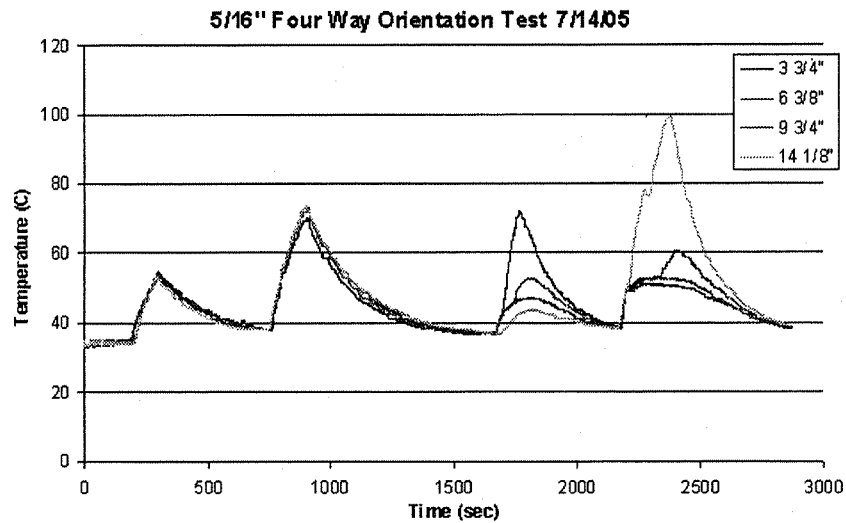


Fig. 4 Tests showing that the 5/16" OD Qu Tube high thermal conductivity heated from below, but essentially the thermal conductivity of copper when heated from above

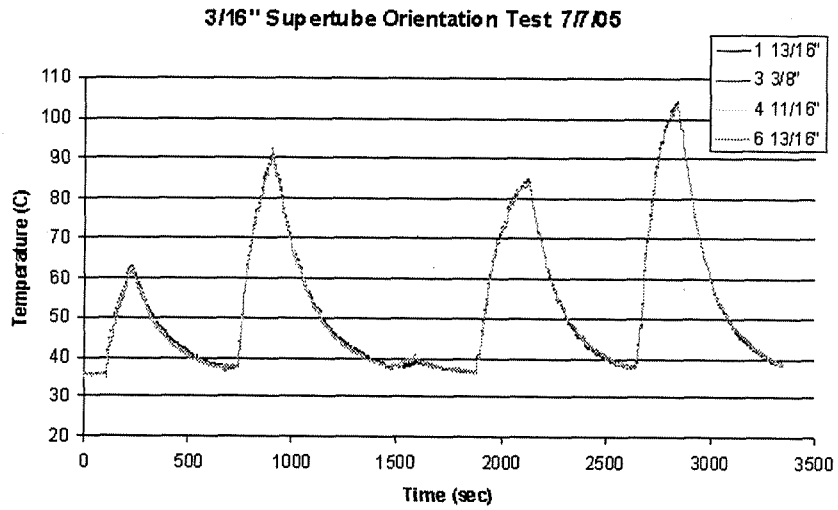


Fig. 5 Tests showing that the 7 7/8" Qu Tube retained high thermal conductivity irrespective of orientation angle and location of the heater

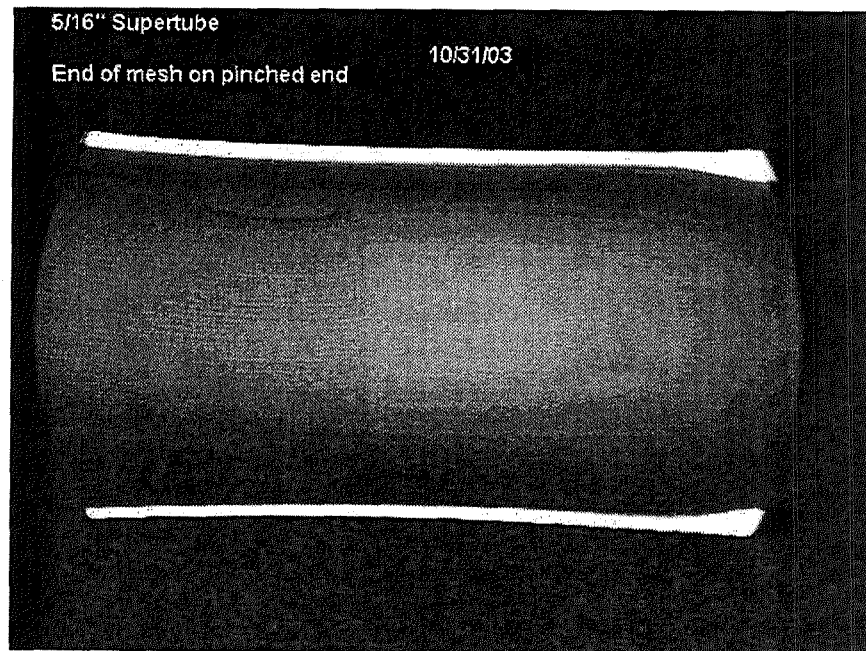


Fig. 6 X-ray of 5/16" Qu Tube showing a fine wire mesh

III. Conclusions

Preliminary results of Qu Tube heat pipes we are testing show high thermal conductivity, with lower bounds as determined by the fin equation of the order of 10,000 to perhaps 30,000 times that of copper (e.g., 339 w/m-K). Two types of tubes have been tested, one with gravity dependent orientation, in which heating from either end, with the heat source located at the top, results in behavior that is essentially that of copper, whereas heating from below, for either end, results in an essentially constant temperature distribution. The gravity independent type exhibits high thermal conductivity irrespective of heat source location or orientation. We have found no indication that the Qu Tube operates as a conventional liquid-vapor or pool boiler heat pipe. We are finalizing the setup for our calorimeter and thermistor rakes, to test the 10' long tubes under controlled conditions, at relatively high heat rates, and we expect to have additional results in a matter of a few months.

Acknowledgments

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